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A DEEP-SEA RADIO TELEMETERING OCEANOGRAPHIC BUOY

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Technical Report
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Director

A DEEP-SEA RADIO TELEMETERING OCEANOGRAPHIC BUOY[1]

1. Introduction

During the spring of 1953 an attempt to make direct measurements of surface currents set up in the middle of the ocean by natural variations in strength and direction of the winds ended in failure. The CARYN turned out to be too small a vessel to work in the heavy weather of the winter North Atlantic, most of her time was spent hove-to, and the measurements obtained were scattered and pitifully few.

Recognizing how desirable it is to obtain such data, however, we determined to devise some means of obtaining it which would not be subject to the disadvantages of a small vessel, or to the great expense of a large ship. After considering all the possibilities that we could imagine, we decided to build twenty radio telemetering buoys to set adrift from the island of Bermuda. These buoys carry the necessary oceanographic instruments to measure current and wind. They were built during the summer of 1953, shipped down to Bermuda in September, and since October 21, 1953 we have now had a nearly continuous series of deep-sea current measurements up until the date of this writing (January 15, 1954). The results of these measurements will appear in a separate Technical Report in the near future when five months of observation will have accumulated. The present report is confined to a description of the buoys, and a discussion of their performance, to date, when launched into the ocean.

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[1]A report of work done at the Oceanographic Observatory, a field station of the Woods Hole Oceanographic Institution devoted to synoptic studies of the Northwestern Sargasso Sea.

II. Buoy Assembly

A sketch of the complete buoy assembly is shown in Figure 1. The over-all height of the buoy from the top of the antenna (a) to the bottom of the buoy casing (b) is 18 feet. The horizontal distance between the ends of the outrigger arms (x) is 12 feet. The buoy weighs about 800 pounds. Before entering into any detailed discussion of the construction of any individual elements, it is probably advisable to describe briefly the over-all assembly of the buoy.

The radio antenna (a) is a center loaded marine type (Premax V antenna #3BIS-25, with loading coil) which is fixed by means of a lead-through bolt to a fine linen formica insulator (f) turned out of a 6-inch length, 2-inch diameter formica rod; the lower half of this formica rod is reduced in diameter to 1.90 inches, so that it fits snugly into the top of the mast tubing. The top of the insulator is tapered to help shed moisture, and the whole antenna and insulator are sprayed after assembly with acrylic plastic spray. The antenna is connected to the transmitter through the interior of the mast tubing by means of automobile ignition wire. The four-cup wind anemometer (w), the wind vane (v) and the navigation light (l) are all mounted on an aluminum cross-arm made of 1½-inch aluminum angle. This piece of angle is bound to the mast tubing by an ordinary automobile muffler clamp (Chevrolet replacing part #3693811). The four-cup anemometer is the cheapest kind available, made by M. C. Stewart, but provided by him with special 1/2-mile contacts (Stewart's stock model has 1/60-mile contacts). Other than sealing the conduit housing and miscellaneous smaller holes with Permatex, no special precautions to keep out salt water appear to be necessary. It is necessary to provide a pipe flange and close nipple to mount the anemometer on the mast. The light

fixture (1) can be any marine exterior fitting which is at hand. The wind vane was made up specially (Section V). The arrow itself was purchased from Stewart. A Model J Helipot 20K Potentiometer is fitted with an extension brass shaft turning inside a brass tubing about 6 inches long. The entire assembly with electrical leads attached is potted in Scotchcast. When this is assembled with the shaft pointing downward, there appears to be very little possibility of moisture working up into the potentiometer winding. The Model J Potentiometer is provided normally with its own ball bearings and is very well built and suited for the severe mechanical wear which it endures over the period of use of the buoy.

A specially constructed magnetic remote reading compass (c) is clamped to the mast by a special non-magnetic bracket (details of the compass are given subsequently). The mast itself is 6 feet of stock Alcoa aluminum tubing, 2 inches O.D. and 1.90 inches I.D. (#61 ST-6). This mast (m) is fastened to the top cover plate (t) of the buoy by slipping it over an iron fitting welded to the cover plate. This iron fitting consists of an 18-inch, 1½-inch (nominal size actually 1.90-inch diameter) pipe welded upright and supported by three welded braces. The aluminum mast fits very snugly over the iron pipe and can be clamped with a muffler clamp. Although the antenna wire is led down inside the mast, through a hole drilled through the cover plate inside the 1½-inch pipe, the leads for the meteorological instruments, compass and light pass through a 2-inch pipe coupling (p) which is welded to the cover plate, through small holes in the cover plate and thence into the interior of the buoy. The lead-through is made watertight by filling the pipe coupling with potting compound (Ozite B). The top cover plate (t) is made of ¼-inch steel plate and fastened to the flange on the top of the buoy

case (b) by 26 3/8-inch bolts. Inside these bolts and resting on the flange is a gasket made of Garlock 95 packing ($\frac{1}{2}$-inch square cross-section). When the bolts are taken up tight, this packing is compressed to $\frac{1}{4}$-inch thickness. There has been no difficulty with water leakage problems. The buoy casing (b) itself is made from a sheet of 1/8-inch thick steel plate 5 feet x 6 feet. This is rolled into the form of a cylinder 5 feet long and 6 feet in circumference, and welded inside and out with a slightly concave bottom. Two handles (h) are welded on the sides, and two pieces of strap (s) iron $1\frac{1}{4}$ inches x 3/8 inches are welded on opposite sides for the purpose of fastening the out-riggers to the buoy. The out-riggers (i) themselves are constructed of $1\frac{1}{4}$-inch angle iron. The current meters and drags are suspended from the small lengths of chain (x).

In order to prevent the buoys from becoming a menace to navigation a sinking device is incorporated into each buoy. The top cover is drilled and tapped to take a $\frac{1}{2}$-inch galvanized iron pipe plug. This plug is drilled with a hole 0.20 inches in diameter, into which is fitted a 1-inch long magnesium alloy bar, well smeared with Permatex. Tests in Ferry Reach show that this bar eats all the way through in from four to six weeks; the buoy then fills with water and sinks.

III. Rotor, Drag and Current Log

In designing a current meter for use on an unattended instrument where it is not possible to make repairs or adjustments, or to clean the blades of the meter, if they are clogged with seaweed or other floating debris, it is important to emphasize simplicity of form. Carruthers made a vertical log for suspension from light ships, the current measuring element of which was

a series of nine hemispherical cups rotating on arms about a vertical axis. After a few experiments with this vertical log, it seemed to us somewhat cheaper to use a large sheet metal rotor, such as shown in Figure 2. Each blade is in the form of a semi-circular cylinder of 6-inch radius. The sheet metal is 0.030 inches thick, galvanized iron. Along both the upper and lower edges there is a preformed iron strap riveted to the sheet metal. This rotor, which is, after all, nothing but an outgrowth of the Carruthers vertical log, has proved fairly trustworthy. It does not bend, it does not foul up with debris, and it is sensitive to currents of as little as a tenth of a knot. Moreover, when this rotor is pulled up and down by waves, it does not turn around from this cause alone, as a propeller-type current meter might very well do. Thus, there is every reason to suppose that the irregular vertical motions of the rotor, which are the inevitable accompaniment of wave action, do not give rise to a false velocity.

The drag, which is suspended from the buoy to a depth of 100 feet or more, is shown in Figure 3. It consists of a 12-foot length of 1½-inch angle iron, to which are bolted two cross-vanes of the same sheet metal from which the rotor is made. The combined area of these two cross-vanes is roughly equal to that of the buoy and rotor. In order to prevent the drag from executing violent skeetering motions, two or more ends of the vanes are bent over.

A schematic diagram of the current log is given in Figure 4. The case of the current log consists of a 3-inch black pipe nipple (n), closed at both ends by 3-inch pipe caps (c). The upper pipe cap is suspended from the outrigger chains [(x) of Figure 1] by the welded eye bolt (b). Another eye bolt (b) is made fast to a vertical shaft passing through the lower

pipe cap and riding on a stainless deep groove ball-bearing race (r). The vertical axle passes through a universal joint (u) to a gear train (g) which consists of six gears (#60-12-NS Tiny Atom motor gears from the following toy company: Wilson's of Cleveland). After this gear reduction of 3,125 to 1, the motion is transmitted to a Model G Helipot Potentiometer (p). The gear assembly and potentiometer are mounted on circular plates (s) which, in turn, are supported by pillars (t) from the bottom of the case, a construction similar to that used in clocks. Ordinary demolition cable (w) is used as an electrical conductor to the buoy, and passes out from the current log through the bottom through a tubing-pipe adapter (Edelmann fitting 3/8 to $\frac{1}{4}$, B-68). The entire device is filled with No. 30 oil. Inasmuch as the construction is similar to a submarine bell, and since the oil is lighter than seawater, there is no tendency for the works to be exposed to salt water even though there is room for the salt water to get through where the shaft enters the lower pipe cap.

IV. Loading Diagram

In loading the buoy, it is essential to keep the weight as near to the bottom as possible. Otherwise, the motion of the buoy in a seaway is very violent (Figure 5). About 100 lbs. of cast iron (W) is placed in the bottom of the buoy casing before anything else is put in. The B batteries (14 45-volt Burgess B batteries, Type 10308) are stacked in two 7-battery piles inside of a wooden box. The A batteries (48 #6 Telephone dry cells) are fitted into the remaining space, as shown by A (Figure 5). Additional batteries to run the clock and navigation light are placed in the remaining space above the B batteries, and a plywood disc is fitted to both the bottom and the top of the battery-pack to hold it rigidly inside the buoy

casing. The space (T) above the batteries is reserved for the electrical system of the buoy (transmitter, relays, etc.).

V. Electrical Circuits in the Buoy

Figure 6 is a schematic diagram of the electrical system inside the buoy. On the left of the diagram various power supplies are shown. The separate clock battery is connected to the clock system at all times. Every three hours, the clock system sends a pulse of three-seconds duration to the stepper assembly. This pulse causes the stepper assembly to move a switch through 22 different positions. This switch is double pole. The upper bank of poles is used to connect various sensing elements to the transmitter, one after another. The lower bank is used to perform certain functions, such as providing a time-delay in the application of the plate voltage to the transmitter. The stepper assembly also turns on the filaments of the transmitter. After the stepper assembly has gone through its complete program of 22 contact points, it stops going, and resets itself until it receives another pulse from the clock system.

The clock system itself is shown in Figure 7. The clock is an automobile clock. Because the exact duration of contact made by the clock is bound to be somewhat uncertain, the clock switch is made to charge a condenser through a high resistance relay which remains energized for three seconds only.

The anemometer log (Figure 8) is a simple pawl and ratchet, operated by a solenoid connected to the anemometer contacts. The ratchet drives a Model G Helipot Potentiometer. In this way, the number of half-mile contacts accumulated since the previous transmission is indicated by the change in resistance reading of the potentiometer.

The compass is shown in Figure 9. It is an ordinary (Corsair) boat compass with the card removed. Small silver contacts are fitted to the needle support, and below these contacts, surrounding the pin, are mounted a potentiometer resistance element and a circular commutator ring. Normally, the contacts do not touch either the commutator ring or the potentiometer resistance element, but when a 6-volt battery is applied to the ends of a solenoid wrapped around the inside of the compass housing, the needles are sharply dipped and contact is made between the commutator ring and the potentiometer resistance element. The exact resistance value, of course, is an indication of the direction in which the needles were pointing. The solenoid is operated from the lower bank of the stepper assembly.

The detailed wiring of the stepper assembly is shown in Figure 10. Normally, all of the relay coils in the stepper assembly are de-energized. Terminals S-3 and S-13 are connected to ground. S-2 is connected to +6 volts A supply, and terminal S-6 is connected through an external resistance of 47,000 ohms to +300 volts in the B supply. Terminals S-7 and S-12 are connected to the negative side of the B supply, which is normally isolated from ground. The whole stepper mechanism program is initiated by the momentary closing of the high resistance relay contacts in the clock system (Figure 7), which establishes an electrical path between terminals S-1 and S-2. This energizes the coil in the start-stop relay, which closes contacts (a) and (b). When contact (a) makes, it locks the start-stop relay in an energized position even after the electrical pathway between terminals S-1 and S-2 ceases to exist. It also turns on the filaments of the transmitter through terminal S-4, and establishes one side of the circuit necessary to energize the plate control relay, but does not turn it on immediately.

When contact (b) supplies 300 volts to the high resistance timer-relay, the coil does not energize until the capacitor is fully charged, at which time contact (c) closes and this, in turn, energizes the stepper relay coil. The wipers on both the upper bank and the lower bank of the stepper relay now advance one step. At the same time, an additional contact (d) on the stepper relay coil armature makes, discharges the condenser, and hence de-energizes the coil in the timer-relay, which opens contact (c) again. This cycle of alternation between the timer-relay and the stepper relay continues for a complete revolution of the wipers in the stepper relay. At one point in the cycle, the wiper on the lower bank momentarily grounds the other side of the plate control relay coil, which is then locked in the energized position by contact (e). The plate voltage is now applied to the transmitter through the B minus side of the battery through contact (f). The stepper assembly finally ceases operation when the wiper in the lower bank reaches a contact which shorts out the A supply to the start-stop relay, at which moment contacts (a) and (b) drop open, and the stepper assembly is again de-energized. The various standard resistors and resistance elements of the various instruments on the buoy are connected one by one by the wiper in the upper bank to the audio oscillator circuit of the transmitter through terminal S-8.

The transmitter wiring diagram is shown in Figure 11. The transmitter consists of a crystal oscillator, parallel connected final amplifier, clamp tube modulator and audio oscillator. The tubes are of the "instant heat" type requiring only 5 seconds for warm up operation.

The clamp tube system of modulation was chosen to simplify the construction and reduce the cost of the transmitter. The final amplifier draws 125

milliamperes at 600 volts with a useful power output of 30 watts. The total B power drain is 180 milliamperes at 600 volts and 34 milliamperes at 300 volts.

The audio oscillator uses a conventional plate-grid feedback system, the frequency of oscillation being controlled by the grid resistance. A change in this resistance changes the RC constant of the grid circuit thus controlling the rate, thus frequency, of plate current pulses through the tube. These pulses generate a voltage of the same frequency across the primary of the feedback transformer which is coupled to the secondary, thence back to the grid in proper phase to reinforce the original plate current change, thus sustaining oscillations. This form of oscillator was chosen as representing the simplest configuration capable of providing a reasonable frequency change with the 20K ohm change available from the sensing elements. The oscillator stability is improved slightly with A and B voltage regulation.

Tuning is accomplished in a conventional manner, the crystal oscillator detuned approximately 1/3 from its peak reading for maximum stability and fast starting time. The final amplifier is tuned for minimum plate current, as read across a ten ohm resistor in the plate circuit, while the antenna loading tap is increased, until a final value of 125 milliamperes is obtained.

VI. Receiving Station

The receiving station is arranged to operate automatically. A schematic diagram of the arrangement in use at present is given in Figure 12. A directional antenna array is connected through an antenna switching relay to a National NC183D receiver, which is operating all the time. Three outputs are taken from the receiver: one to an audio-amplifier and thence to a loudspeaker for constant audible monitoring of the frequency; the second output

passes through a selective band pass filter (Spencer-Kennedy), and thence through the amplifier of the Magnecorder. The output of the amplifier is thus continuously available for tape-recording. However, it would be a great waste of tape to have the tape-recorder operating at all times. Therefore, a circuit has been arranged for turning on the tape drive only during a transmission from the buoy. This is affected by the third output from the receiver, which passes through a National Select-O-Ject tuned to 440 cycles. The output of the Select-O-Ject operates a vacuum tube relay which, in turn, turns on a motor-driven pulse generator, which drives a stepping relay as long as the vacuum tube relay is energized. The stepping relay is reset to its initial position, if there is any interruption in the 440 tone. Thus, bursts of white noise, such as static or heterodynes from nearby c.w. stations may initially set off the vacuum tube relay and start the stepping relay, but due to the normal short duration of such 440 tones, the stepping relay is normally reset before it can trigger the 30-second timer. This consists of an electric clock which drives a cam. The cam operates a switch which runs the clock and, therefore, the clock turns until it reaches a dead position of the cam and then stops. When the stepping relay reaches a high number of steps, it turns on the clock despite the fact that the clock is on the off position of the cam, and keeps the clock going until the cam comes off the dead position. The clock then continues to go for 30 seconds. Since the tape-recorder is in parallel with the clock motor, it also runs for 30 seconds before turning off. Near the end of the 30-second period, a time-tone (whose frequency is different for each hour of the day) is also put onto the tape. Normally, the sequence of events during a buoy transmission is first a 440 cycle tone for triggering purposes; next, 4 or

5 standard resistor tones and then tones corresponding to the compass, vane, current log, anemometer log, compass again and then whatever other special sensing elements there may be on the buoy (thermistors, pendulums, leak detectors have been used to date).

In reading the records, it has been found that the frequencies of the tones cannot be read directly on any electronic counter. This is because of the inevitable background noise, especially as the range of the buoy becomes more and more extended. Therefore, the most practical method of reading the records has been to play back the tape displaying the output on the (x) co-ordinate of an oscilloscope, at the same time beating a Hewlett-Packard audio oscillator on the (y) co-ordinate. The exact frequency of the oscillator is then read by a Potter electronic frequency-time counter. The over-all precision of the telemetering system, allowing for all the possible sources of error between the actual electrical resistance in the buoy to the final reading from the calibration curve seems to be something like plus or minus 0.5%.

VII. Field Tests of the Buoys

A discussion of the oceanographic data obtained by these buoys and calibration of the rotors will be given in a later Technical Report. However, it seems advisable to exhibit, at this time, certain buoy statistics. Table 1 shows just what happened in using 8 buoys during the period of September 29 to January 15.[2] It is also instructive because of the various lessons that were learned. The reader will see that two of the buoys were used several times. The first buoy that gave mechanical trouble lost part of its

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[2] The buoys were put out by the PANULIRUS, vessel of the Bermuda Biological Station, the fathometer and other equipment supplied under Contract Nonr-1031 (00).

Table 1. Buoy Statistics - September 29, 1953 to January 15, 1954

Buoy No.	Type Rig	Date Launched	Total Days Operation	Days of Good Data	Ultimate Fate	Remarks
1	Anchored in reach	Sept. 29	6	Test only	Reused	
1	Free drifting	Oct. 7	8	RDF only	Washed up on sandy beach and reused	Antenna broke off; all further ones brazed in one piece
1	Experimental wave buoy	Nov. 27	10	10	Old batteries wore out	
2	Anchored off South Shore in 30 fathoms	Oct. 12	3	2	Picked up and reused	
2	"	Oct. 16	3	0	"	Audio oscillator circuit troublesome; all further ones redesigned
2	"	Nov. 9	7	7	"	Now works well
2	Free drifting	Nov. 23	11	11	Presumed shot and sunk	Worked very well
3	"	Oct. 21	21	21	Drifted out of radio range	Worked very well
4	"	Oct. 28	11	11	"	After 4 days compass failed apparently due to oil leak; now heavy oil used
5	"	Nov. 17	2	0	Wrecked on rocks in surf and examined	The clock did not turn switch; new microswitches now used
6	"	Dec. 30	16 and still running	16	Perfect to present	Perfect
7	"	Dec. 16	32 and still OK	11	Drifting out of radio range, but still audible	Perfect but too distant to read all data
8	"	Dec. 5	42 and still OK	10	On reef but still electrically perfect	Apparently dropped drag and wind blew it on reef; now heavier wire used

antenna. From that time on we brazed the antennas into one solid piece. Buoy #2 suffered, at one time, a considerable amount of trouble in the audio oscillator. The audio oscillator was redesigned, and we have had no more trouble from that source. Buoy #4 suffered from a defective compass. All indications are that the light kerosene in the compass leaked out. From that time on we have used No. 30 oil, and we have had no further compass trouble. Buoy #5 was a complete loss because of a defective clock system. It is believed that this difficulty has now been surmounted by using more sensitive micro switches on the clocks than were previously used. The loss of the deep drag on buoy #8, after 10 days of operation, is probably due to a combination of heavy weather and an old BT cable. This difficulty is probably taken care of by using heavier wire rope.

A typical example of the resistance-frequency relationship in the buoy transmitter is given in Table 2. These frequencies are quite stable over a long time. Fortunately there is available a long term example under actual operating conditions: Buoy 8 dropped its deep drag and anchored itself somewhere on the reefs. The frequencies of the standard resistors over 48 days of transmission 16 times daily are given in Table 3.

Deep-sea observations by these buoys were started on October 21. From October 21 to January 15, there are 86 days. During this interval, we have had seven buoys out, and obtained 85 days of complete and usable oceanographic wind-drift-current data. Of course, some of these days represent days when two buoys were out at a time, so that the actual length of time is not such a complete coverage as may first be expected by looking at these two figures. However, there is an interesting practical lesson to be learned from our experience with these buoys. First, that they are able to

Table 2

Resistance-Frequency Relation
for Buoy 6

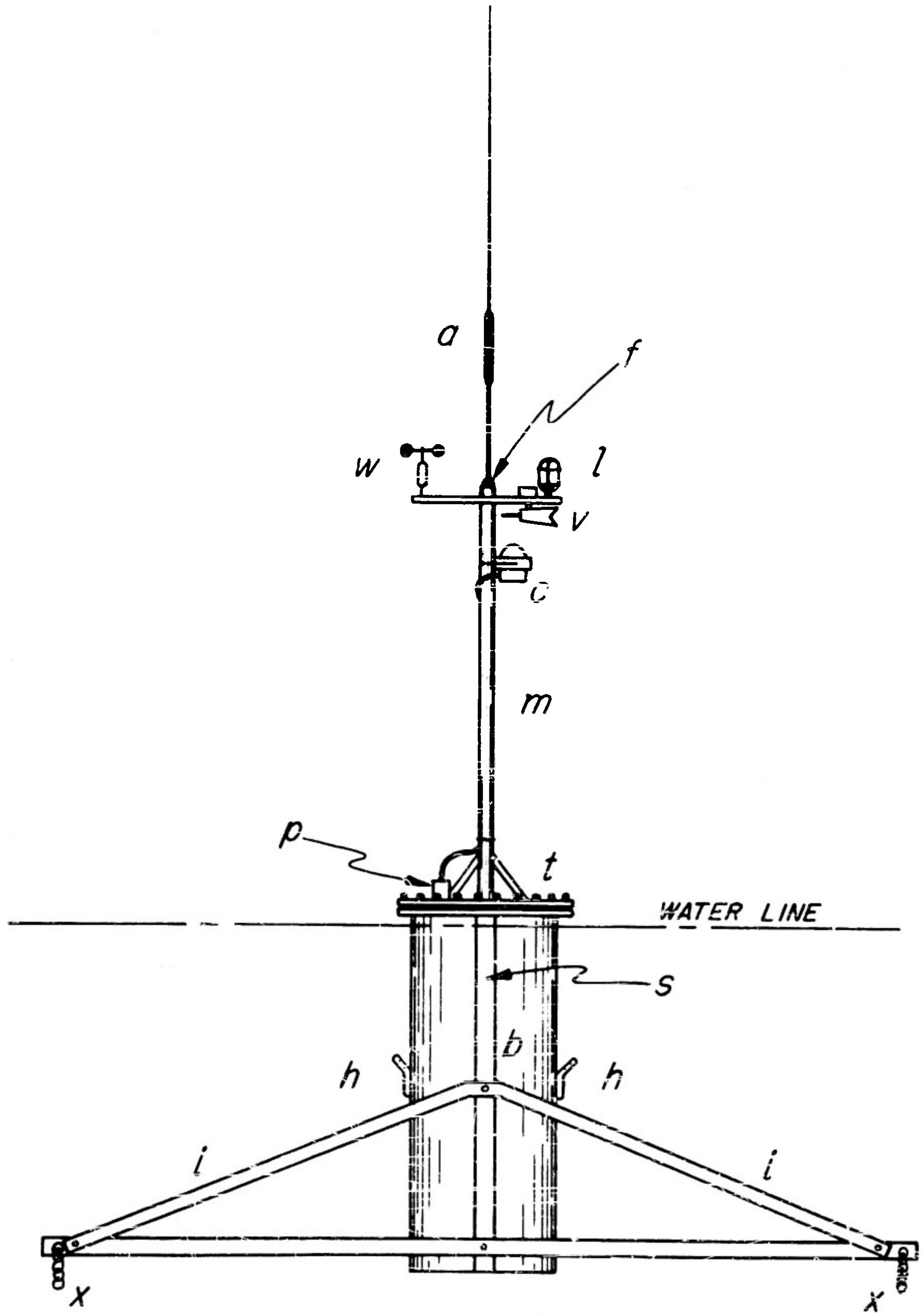
ohms	cycles/sec
0	2203
2000	1784
4000	1533
6000	1382
8000	1264
10000	1186
12000	1120
14000	1070
16000	1018
18000	982
20000	938

Table 3

Standard Resistor Frequencies of Buoy 8
for a Period in the Ocean of 48 Days

Month	XII	XII	I	I
Day	5	15	5	22
Days out	0	10	31	48
No. transmissions	10	170	506	780
Frequencies	2401	2487	2426	2513
	1826	1893	1854	1877
	1399	1427	1409	1418
	1275	1291	1281	1283
	1057	1070	----	1061

operate satisfactorily and continuously for longer periods of time and in heavier weather than any present oceanographic vessel. For example, the buoys operated perfectly during the storm (January 13) in which the VEMA almost foundered. It would be difficult to find a similar period in the history of oceanographic ship operations which could show such a concentrated amount of deep-sea work in the same length of time. Secondly, the matter of economy enters in. The cost of each buoy is about $600 (exclusive of salaries and expenses of the scientific staff). These seven buoys (including the failures which, of course, we will not have to include in the future) cost $4200. The cost of obtaining this data is, therefore, $50 a day. Inasmuch as it would be quite feasible to obtain hourly data from these buoys, one can easily be assured that a cost of $2.00 per set of deep-sea oceanographic observations has been definitely demonstrated. Let us contrast this with the most overoptimistic picture of shipborne research of the same variety. Even if we were to suppose that an oceanographic vessel could work in winter weather off Bermuda for 85 out of 86 days, the minimum cost would be something like $700 a day (exclusive of the salaries and expenses of the scientific staff). It, therefore, seems very conservative to make the statement that these buoys can do certain jobs, such as current and thermal studies at less than 5% of the cost of doing the same job by ship, and certainly under much more severe weather conditions.



BUOY ASSEMBLY

FIG. I

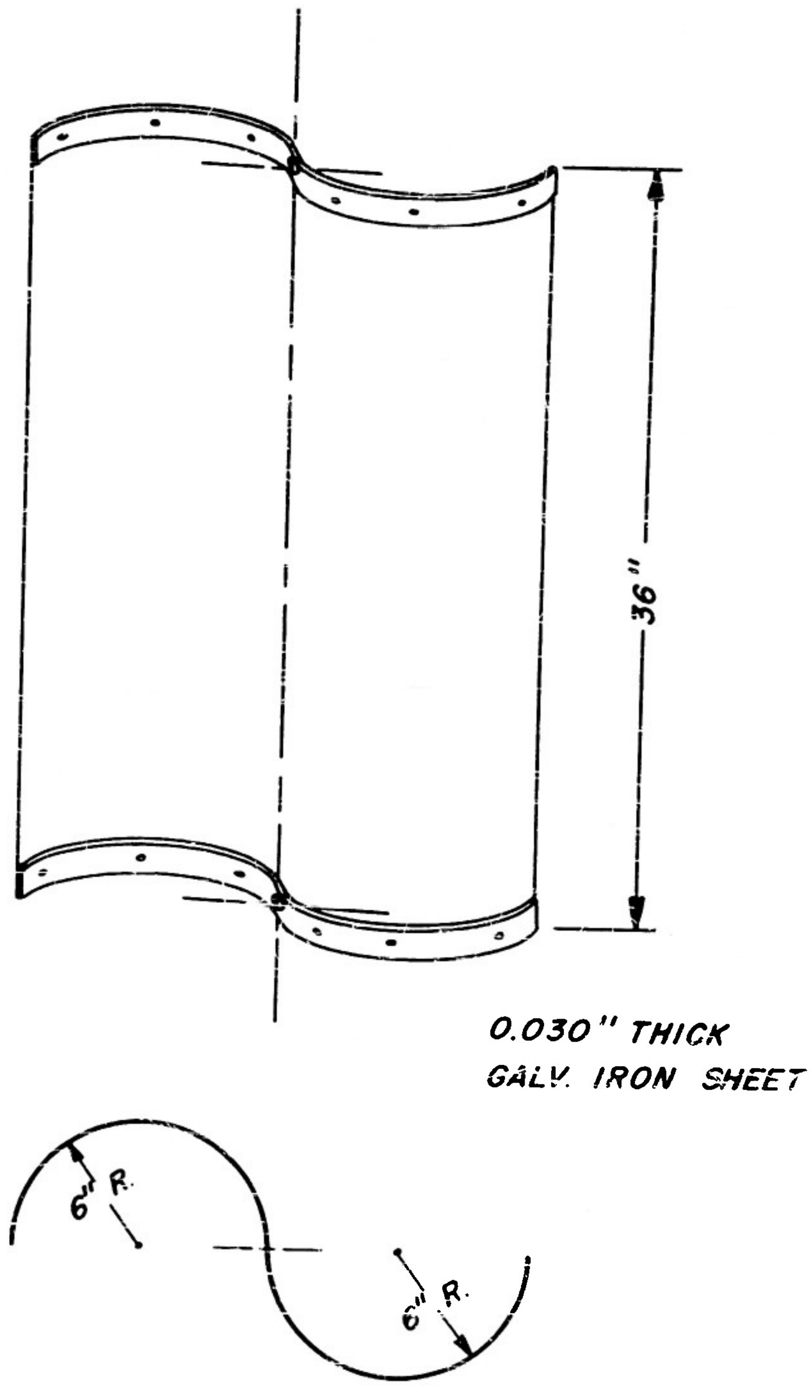
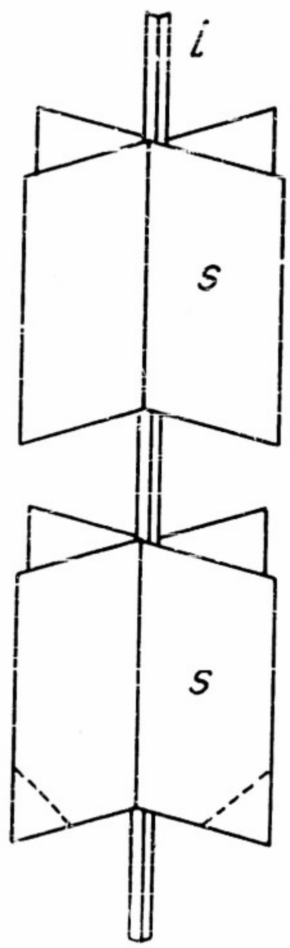
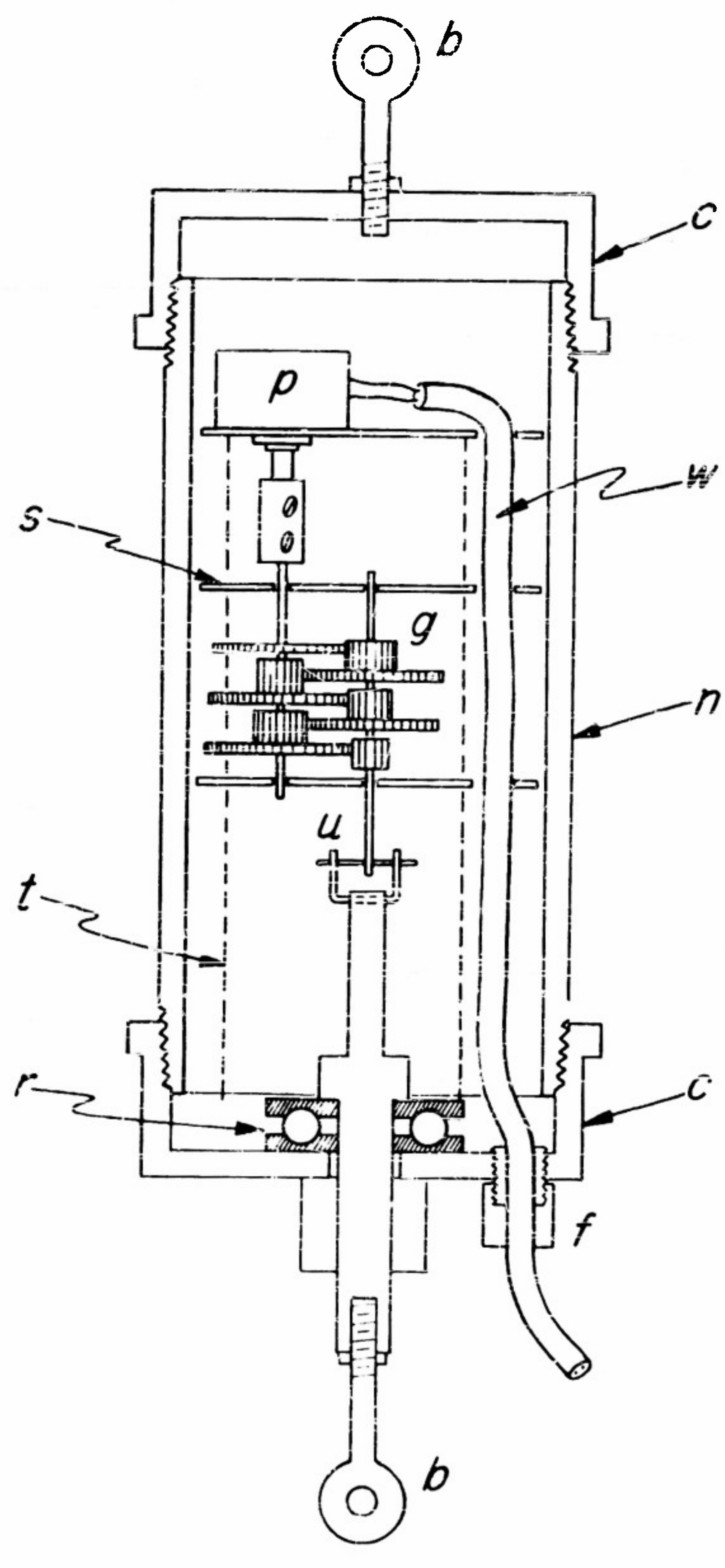


FIG. 2



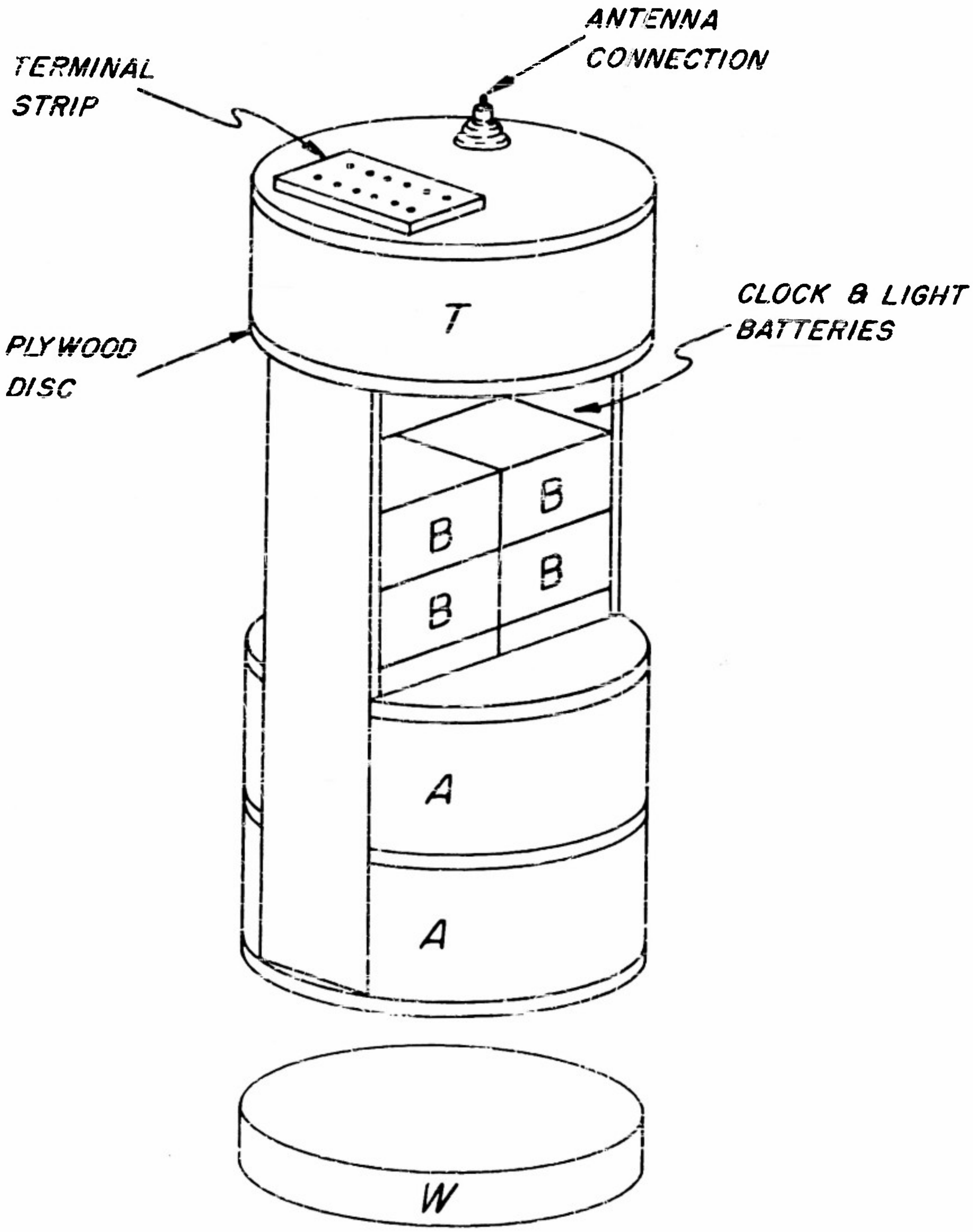
VANE DRAG

FIG. 3



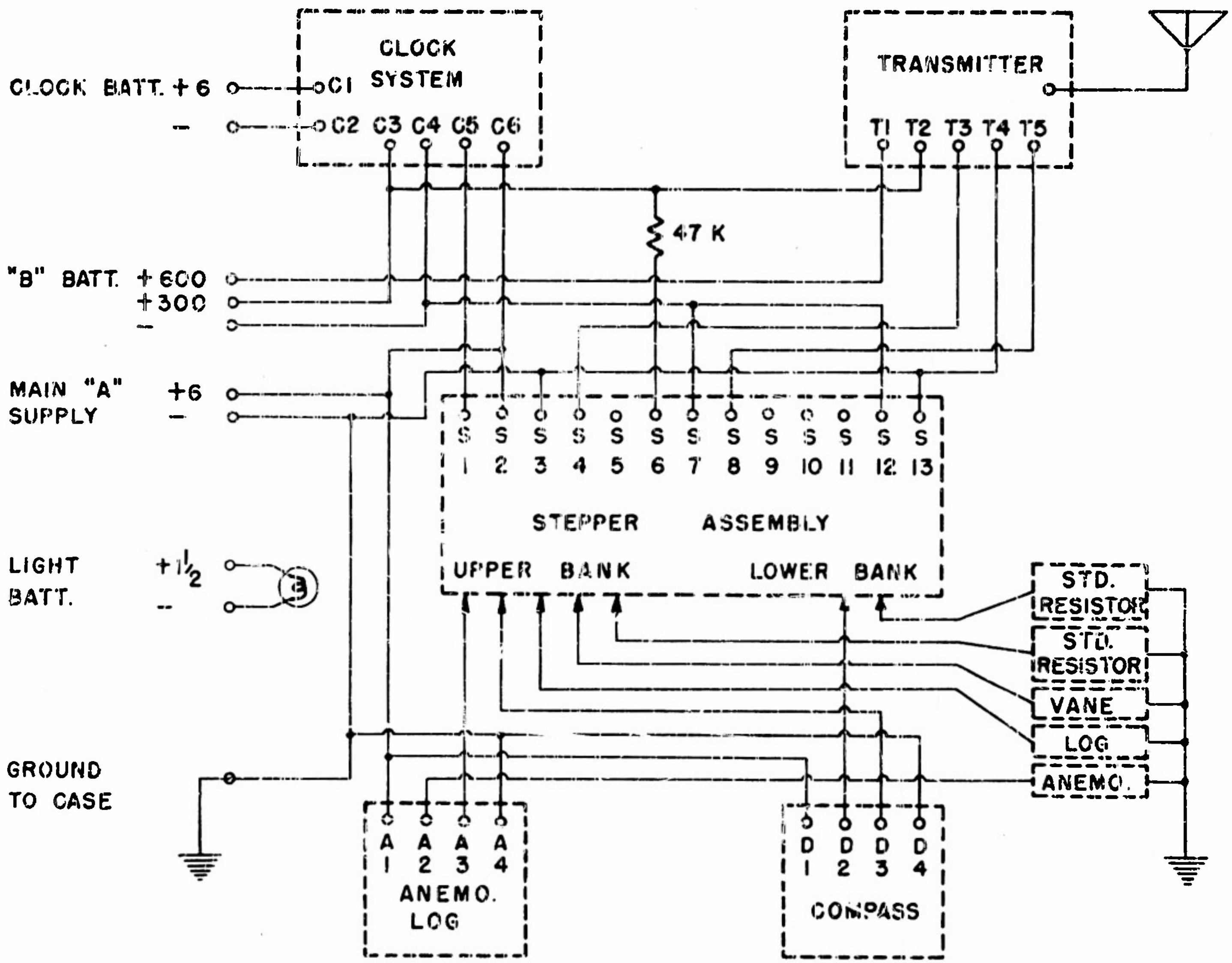
CURRENT LOG

FIG 4



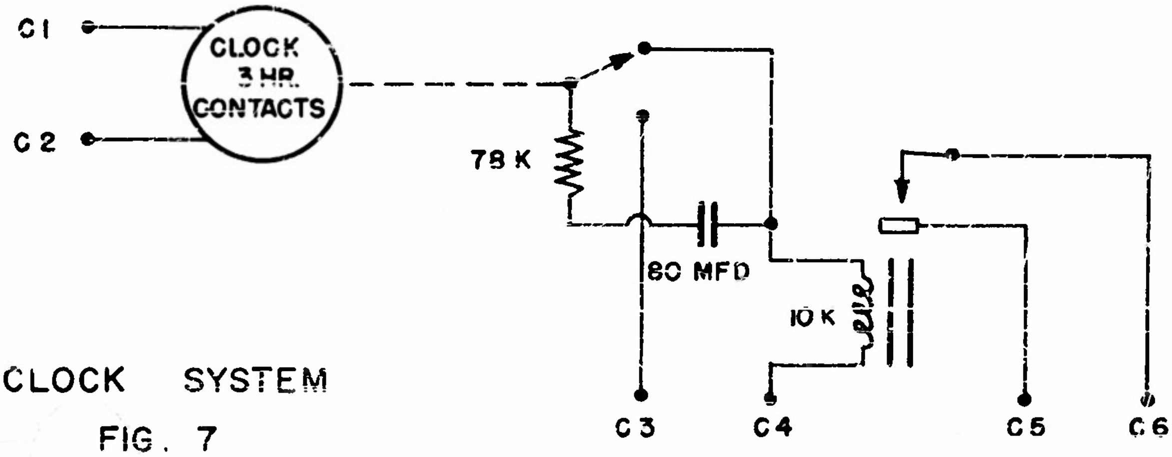
BUOY LOADING DIAGRAM

FIG. 5



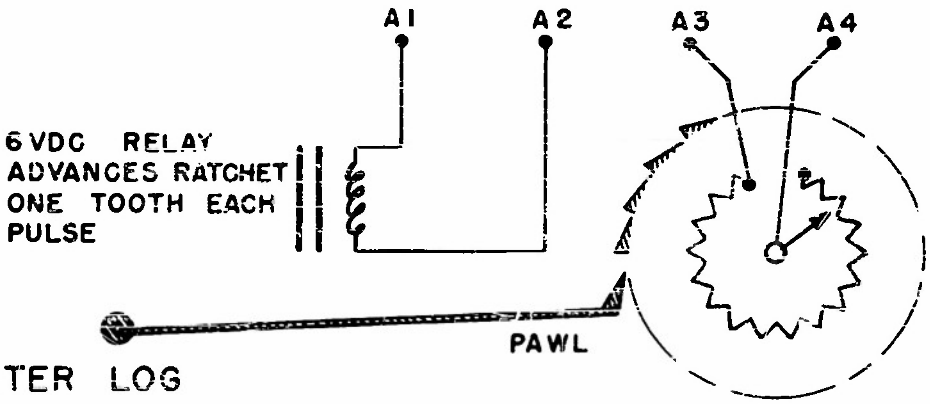
SCHEMATIC OF BUOY

FIG. 6



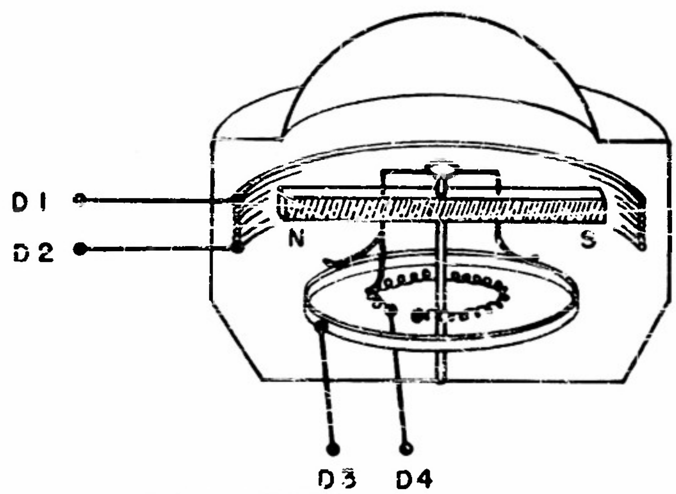
CLOCK SYSTEM

FIG. 7



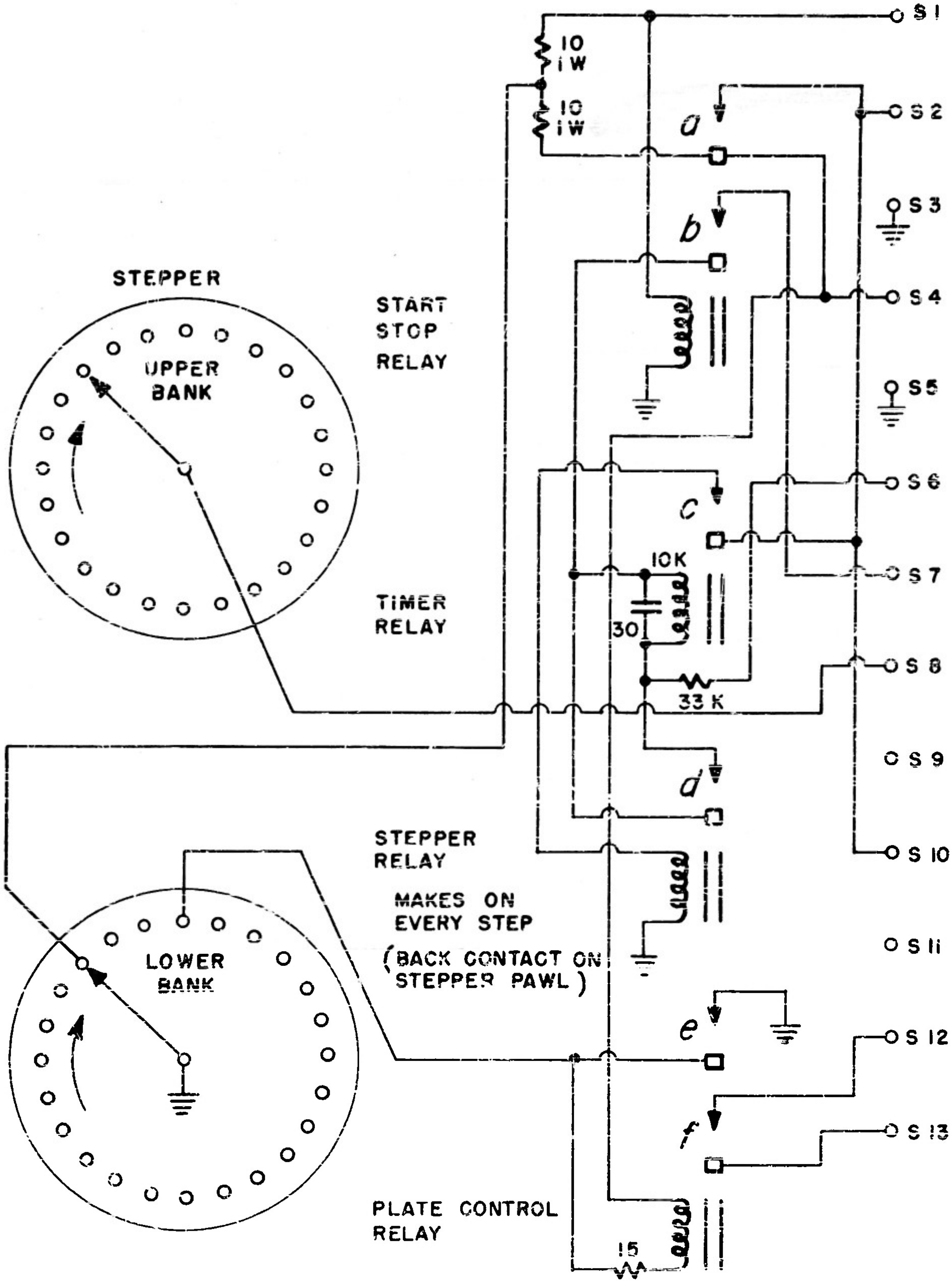
ANEMOMETER LOG

FIG. 8



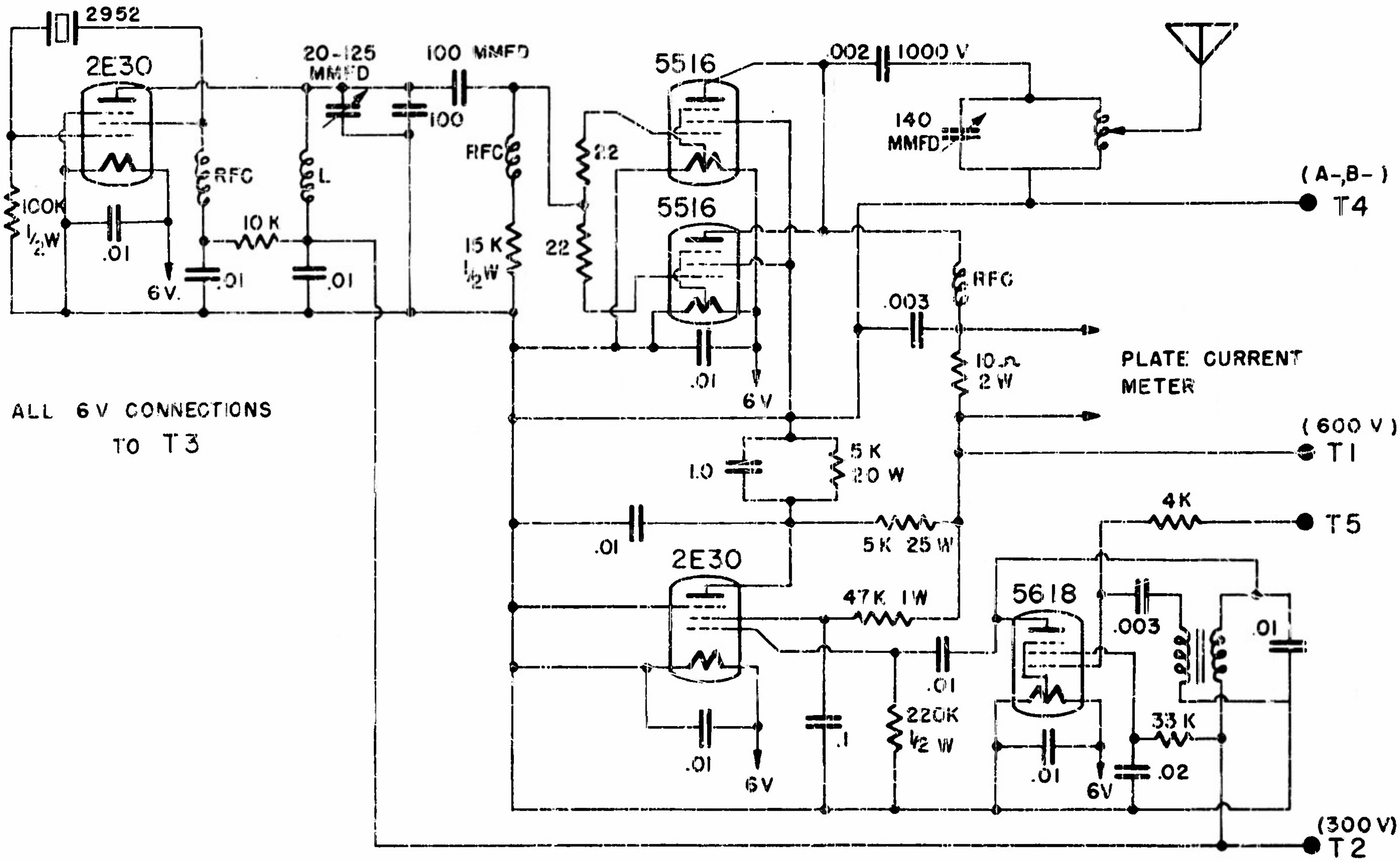
COMPASS

FIG. 9



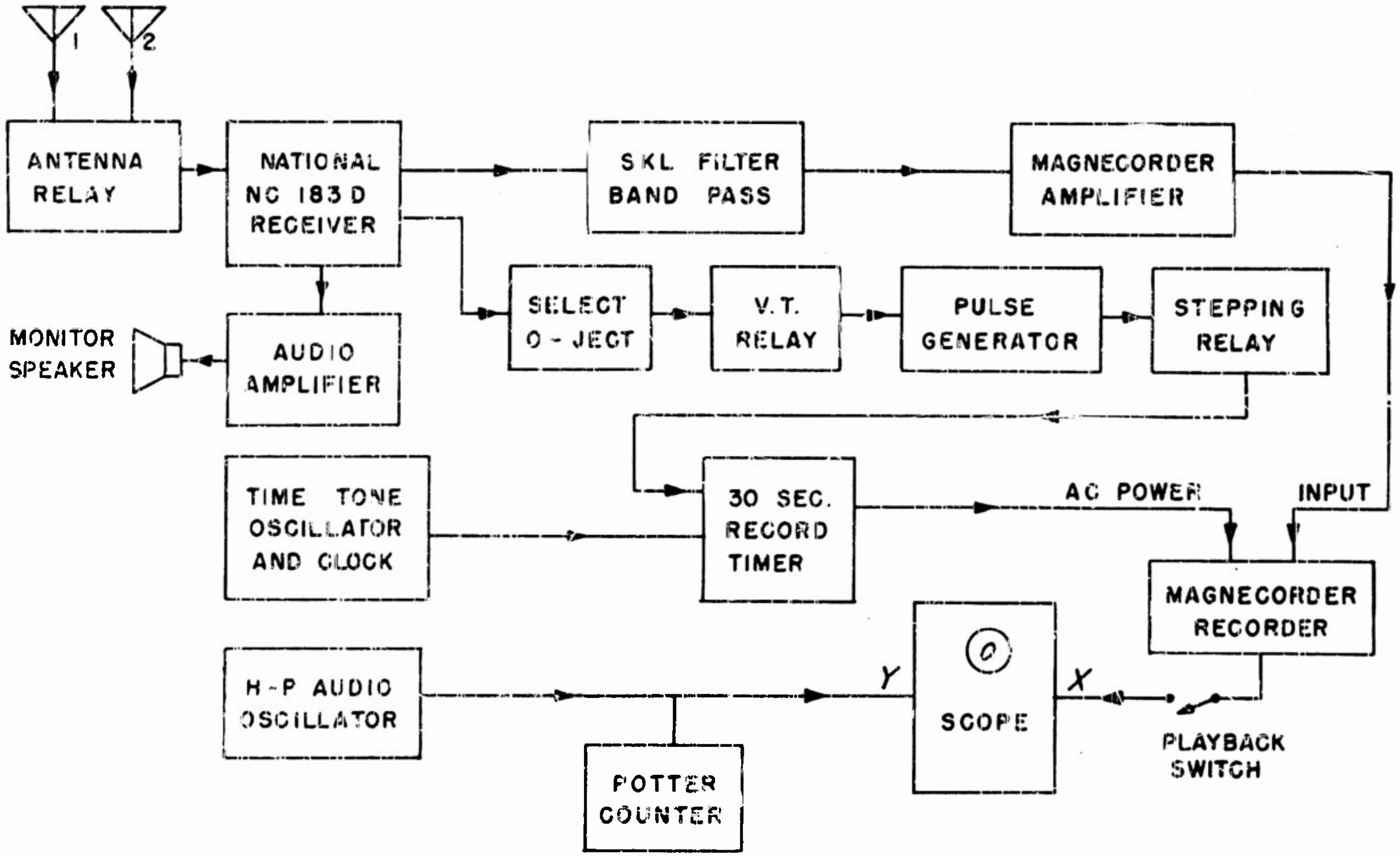
STEPPER ASSEMBLY

FIG. 10



TRANSMITTER CIRCUIT

FIG. 11



RECEIVING STATION SYSTEM
BLOCK DIAGRAM
FIG. 12

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